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Electronic Power Source for Electrolysis

A new constant voltage power supply for use in certain electrolytic determination and separation processes has been developed by the electronic instrumentation laboratory of the National Bureau of Standards. This device, operating from a 110-volt alternating current line, supplies a stabilized and continuously adjustable direct current voltage at current demands up to 2 amperes or more. Regulation is maintained with respect to a reference potential electrode, a principle recognized in recent years as a useful means of selectively depositing only those metals that it is desired to remove in electrolytic separation.

Electrolysis has been used extensively for the separation and determination of certain elements, particularly copper and lead. Another application consists in removing a large variety of metals from a solution so that the remaining constituents may be subsequently determined by some other method. Thus in the determination of aluminum in steel, the mercury cathode serves to remove iron and alloying constituents that might interfere in the analysis.

In most of the above applications no effort is made to control the voltage, and the selectivity of the process is determined by the type of solution in which the electrolysis takes place. Procedures using the more selective method of controlling deposition potential have been limited by the lack of suitable equipment to furnish and maintain the constant voltage required. Although several such devices have been built, they are not entirely suitable because of mechanical features that render their performance uncertain due to such factors as fouling of contacts, or because the electronic circuits used do not permit control under all conditions of operation.

The deficiencies of previous instruments are eliminated by the new power source developed by the Bureau. The voltage is regulated by a carefully engineered and compact electronic instrument that utilizes standard radio-type components. It is designed to produce a controlled output of several volts in loads as low as 1 ohm, though the same techniques could be used in apparatus built for higher outputs. In many applications, the conventional series-regulated power supply is at a disadvantage because of the high load currents that must be handled directly by vacuum tubes.

In the electrolytic separation application for which the instrument was especially designed, it is necessary to control the power supplied to a load, the plating electrode, with respect to the potential of a reference electrode. Too high a potential is indicative of excessive load power. Therefore, the function of the circuit is to reduce its output automatically until the control potential is at the desired value.

Internally, the instrument contains an amplitude-controlled oscillator, a power amplifier and rectifier, and two direct coupled stages of amplification. The oscillator, of the multivibrator type, operates at approximately 2,000 cycles per second, producing a variable amplitude square wave that is amplified by a pair of audio-beam power tubes in push-pull. These in turn

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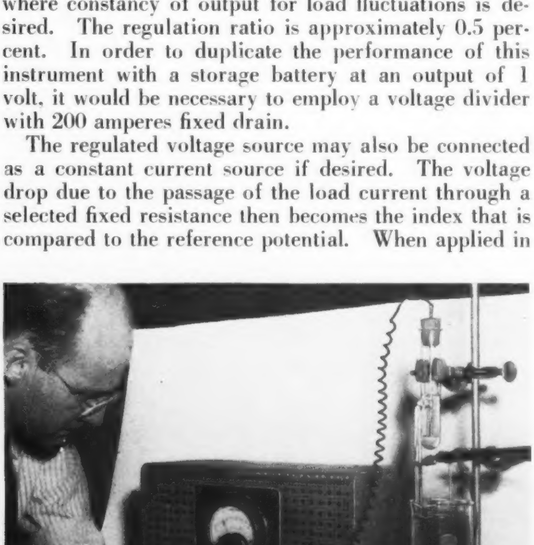
are coupled through a step-down transformer to the low-voltage, high-current rectifier. An inductance and capacitance filter reduces ripple and noise to a very low value. This filtered voltage is the output of the instrument.

For regulation, a portion of the output voltage is compared to a voltage stabilized by a gaseous regulator tube. The difference between these voltages is amplified by the two direct-coupled stages and used to control the amplitude of the oscillator signal. Connections are such that the oscillator amplitude is increased when the output voltage falls below the reference value. With the two stages of amplification, regulation is very precise, so that the output deviates only slightly from the reference voltage.

The reference voltage is adjustable by a control in the panel of the instrument. This control, which therefore acts as the output voltage regulator, has a range of adjustment from 0 to 2 volts, but higher voltages may be obtained by using only a part of the output for comparison. With a suitable voltage divider, a power supply capable of delivering up to 8 volts may be obtained.

As a result of the high degree of regulation, the instrument has a low effective internal impedance. This is about 0.005 ohm when the entire output voltage is used for comparison with the reference voltage. Hence the voltage drop from heavy load currents is small. The low internal impedance of the instrument makes it suitable as a battery substitute in those applications where constancy of output for load fluctuations is desired. The regulation ratio is approximately 0.5 percent. In order to duplicate the performance of this instrument with a storage battery at an output of 1 volt, it would be necessary to employ a voltage divider with 200 amperes fixed drain.

The regulated voltage source may also be connected as a constant current source if desired. The voltage drop due to the passage of the load current through a selected fixed resistance then becomes the index that is compared to the reference potential. When applied in



The electronic power source developed at the Bureau for constant-voltage power supply in electrochemical processes automatically maintains the cathode potential (outer gage electrode) with respect to a reference electrode (dipping into solution).

TECHNICAL NEWS BULLETIN

U. S. DEPARTMENT OF COMMERCE
W. AVERELL HARRIMAN, *Secretary*
NATIONAL BUREAU OF STANDARDS
E. U. Condon, *Director*

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this manner, the instrument offers approximately the same advantage as when used for a voltage source.

One application in which the apparatus has been especially successful is the separation of copper from solutions preliminary to the polarographic determination of very small amounts of cadmium, lead, tin, and other metals. The high degree of control attainable permits separation of elements whose half-wave potentials differ by only a few tenths of a volt. Additional experimentation is in progress in the Bureau's physical chemistry laboratory to determine the full scope of the instrument in electrochemical processes.

New Determination of the Radiation Constant C_2

A new experimental determination of the constant C_2 in Planck's and Wien's radiation laws [1] has recently been made by M. S. Van Dusen and A. I. Dahl of the Bureau's pyrometry laboratory. The value obtained, 1.438 cm-degree, is somewhat higher than that now used (1.432 cm-degree) in the International Temperature Scale [2] and agrees very closely with the most recent values calculated from the atomic constants. This

[1] For further technical details, see Freezing points of cobalt and nickel, M. S. Van Dusen and A. I. Dahl, J. Research NBS 39, 291 (1947) RP1828; or Freezing points of cobalt and nickel and a new determination of Planck's constant C_2, by the same authors, Science 106, 428 (1947).

[2] G. K. Burgess, The International Temperature Scale, BS J. Research 1, 635 (1928) RP22.

result thus adds to the evidence that the most probable value of the constant is 1.438 cm-degrees and that the accepted value should be raised. The assignment of a higher value to C_2, on the basis of such evidence, is one of the more important of the changes proposed by the Bureau in a revised draft of the International Temperature Scale, which will be presented to the International Conference of Weights and Measures this year.

Planck's radiation law

$$J_\lambda = 8\pi ch\lambda^{-5}\ (e^{C_2/\lambda T}-1)^{-1}$$

gives the experimentally observed distribution of energy with wavelength in black body radiation, and the dependence of this distribution on temperature. Here J_λ is the intensity of monochromatic radiation of wavelength λ emitted by a black body at absolute temperature T, c is the velocity of light, h is Planck's constant, and C_2 is a constant. At temperatures attainable in the laboratory the relationship takes the form

$$J_\lambda = 8\pi ch\lambda^{-5}\ e^{-C_2/\lambda T}$$

This equation, known as Wien's distribution law for monochromatic radiation, is of great practical importance in pyrometry, photometry, and colorimetry.

The International Temperature Scale, adopted in 1927 by the Seventh General Conference of Weights and Measures, is based upon a number of fixed points the temperatures of which are assigned. The highest of these is the freezing point of gold, defined as 1,063° C. Above the gold point this temperature scale is extended by solving for "t" in Wien's law of radiation, which takes the form

$$\log_e J_2/J_1 = C_2/\lambda\ (1/1336 - 1/(t+273)).$$

In this equation, J_2 is the intensity of monochromatic visible radiation of wavelength λ cm emitted by a black body at temperature t (degrees Centigrade), J_1 is the intensity of radiation of the same wavelength emitted by a black body at the gold point, and C_2 is defined as 1.432 cm-degrees.

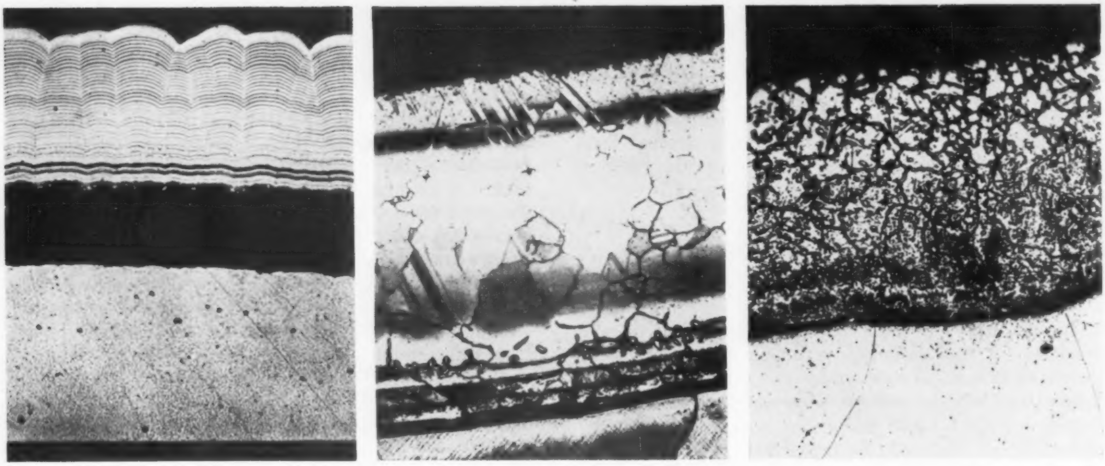
The assignment of the value 1,063° C to the gold point was based primarily upon the gas thermometer work of several investigators about 40 years ago. Among these were A. L. Day and R. B. Sosman, who extended the constant-volume nitrogen thermometer scale up to about 1,550° C by obtaining the freezing points of copper, nickel, cobalt, and palladium. In the present investigation, in order to compare the International Temperature Scale with the gas-thermometer scale, the freezing points of cobalt and nickel samples from the same lots as used by Day and Sosman were determined experimentally on the International Temperature Scale. This was done by focusing the telescope of an optical pyrometer on a black body consisting of an open-end sight tube immersed in the freezing metal. The observed ratios of brightness of black-body radiation at the nickel point and at the cobalt point to that at the gold point were obtained by use of a rotating sector disk, and these values of J_2/J_1 were then substituted into Wien's law to obtain t, the temperature of the freezing metal under investigation.

The freezing points of nickel and cobalt as obtained on the International Scale were found to be somewhat higher than the values of Day and Sosman. However, the determinations of these fixed points by Day and Sosman on the gas-thermometer scale have been accepted as standard for many years. Their values were therefore assumed correct on that scale and after reduction to the thermodynamic scale were substituted into Wien's law together with the experimentally determined brightness ratios J_2/J_1. When this equation was then solved for C_2, the value obtained was 1.438 cm-degree, which is in accord with the latest experimental evidence from other fields.

Since the adoption of the International Temperature Scale in 1927, there has been considerable evidence to indicate that the value assigned to C_2 is low. The International Conference of Weights and Measures was scheduled to consider revision of the temperature scale in 1939 but failed to meet because of unsettled political conditions. One of the proposed revisions was to increase the value of C_2 to 1.436 cm-degrees. Since 1939 there has been evidence that the value should be still higher, and this is confirmed by the results obtained at the Bureau.

The experimental procedure was an adaptation of the "crucible" method for determining the freezing points of metals. In this method, a hollow enclosure, or black body, is immersed in a bath of the metal, and observations of the radiation from the black body are made with an optical pyrometer while the metal is freezing. A high-frequency induction furnace was used as a source of heat, because it provides a high degree of temperature uniformity throughout the sample and minimizes the possibility of contamination by furnace elements. For observations of the freezing points of cobalt and nickel, unfused thoria or beryllia was placed in the closed end of a sight tube (black body) of the same material, which was then immersed in a bath of the molten metal, contained in a crucible also made of the same material. The crucible was surrounded by insulation and mounted in a larger porcelain container. The assembly was kept in a Pyrex glass enclosure, where a helium atmosphere was maintained to prevent oxidation of the heated metals. Similar apparatus was used for observations on the black body at the gold point, except that the crucible and sight tube were made of graphite.

The brightness ratio J_2/J_1 was measured by means of a rotating sector disk of known angular opening. The less bright source was viewed through the optical pyrometer without the disk, and the disk was used with the brighter source. Under the conditions of the experiment, the percentage transmission through the openings of the disk, as computed from measurement of the openings, corresponded to the ratio of brightness J_2/J_1 for the two sources. In addition to the sector disk, a standardized absorption glass was used to obtain temperature measurements at the freezing points of the metals.



Tungsten-alloy electrodeposits obtained by a new process developed at the Bureau are thick, smooth, and quite hard, and retain their hardness at elevated temperatures. The specimens initially show laminations (*A*, iron-tungsten, 250X), that are replaced by a granular structure (*B*, cobalt-tungsten, 100X) upon heating. Heat treatment increases hardness (*C*, same as *B*, 100X), probably as a result of "precipitation hardening."

Electrodeposition of Tungsten Alloys

A method of producing satisfactory electrodeposits of tungsten alloys on metal surfaces has resulted from investigations conducted by Abner Brenner, Polly Burkhead, and Emma Seegmiller of the Bureau's electrodeposition laboratory.[3] Smooth, thick deposits of tungsten alloyed with cobalt, nickel, or iron have been obtained from hot ammoniacal solutions containing organic acids. These alloys are quite hard and, what is more, retain their hardness at elevated temperatures, just as do the similarly constituted cast metallurgical alloys.

The commercial importance of tungsten alloys is directly related to their use in applications—such as bearings, pistons, cylinders, dies, molds, and machine tools—where hardness, corrosion resistance, or high strength at elevated temperatures are essential. Although efforts to electrodeposit pure tungsten have for many years proved unsuccessful, deposits of this metal alloyed with iron, nickel, and cobalt have been produced by various processes. These methods, however, yielded specimens having unsatisfactory physical properties for many uses. Only a thin layer could be obtained, and this was weak because of cracks and oxide inclusions. The development of an improved process for depositing these alloys was therefore undertaken by the Bureau.

Of the alloys investigated, cobalt-tungsten was found to deposit most easily. In some of its properties it resembles the alloy stellite. A typical solution for depositing cobalt-tungsten contains:

Tungsten	25 g/liter (as sodium tungstate).
Cobalt	25 g/liter (as cobalt chloride or sulfate).
Rochelle salt	400 g/liter.
Ammonium chloride	50 g/liter.
Ammonia to a pH of 8.5 to 9.	

Plating takes place at a temperature above 90° C and at a current density of from 2 to 5 amperes per square decimeter. The Rochelle salt may be replaced by salts of other organic hydroxy acids. As anodes, either tungsten, the appropriate iron-group metal, or a tungsten alloy may be employed. Tungsten anodes leave the least amount of residue when they go into solution, and may be used without bags. The solutions for depositing the iron- and nickel-tungsten alloys are very similar to that for cobalt-tungsten.

The maximum amounts of tungsten that may be obtained in this way are 35 percent in the nickel alloy, about 50 percent in the cobalt alloy, and about 60 percent in the iron alloy. However, for sound alloys of desirable properties, the tungsten content must be lower than the maximum. For example, the cobalt alloys should have not more than 30 percent of tungsten.

The nickel-tungsten and cobalt-tungsten deposits have good adhesion to steel and can be plated up to a thickness of 0.02 inch without becoming appreciably nodular. As formed, they are brittle and show a laminar structure under the microscope, but heating to suitable temperatures results in the disappearance of the laminations as the alloys become ductile.

The most interesting feature of the alloys obtained by this process is their hardness, which in the untreated nickel- and cobalt-tungsten alloys may be between 400 and 700 on the Vickers scale. The iron alloy is still

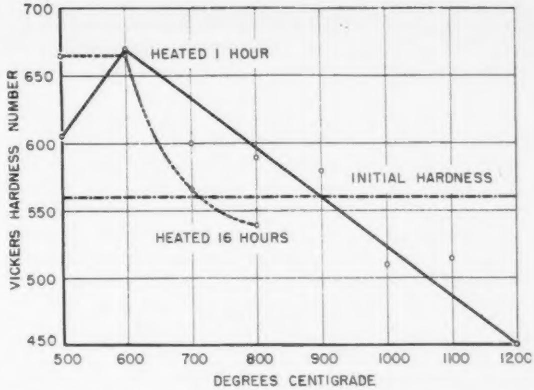
[3] For further technical details, see Electrodeposition of tungsten alloys containing iron, nickel, and cobalt, Abner Brenner, Polly Burkhead, and Emma Seegmiller, J. Research NBS **39**, 351 (1947) RP1834.

harder, ranging from 700 to 900 Vickers; it is thus comparable in hardness to electrodeposited chromium.

Unlike most other electrodeposits, which soften with heat treatment, these alloys may increase 100 points or more in hardness upon heating to 600° C. The cobalt-tungsten alloy is of further interest in that it maintains a fair degree of hardness even at quite elevated temperatures. For example, at 700° C the hardness of a carbon steel drops to about 50 Vickers, whereas the cobalt-tungsten alloy at this temperature has a hardness of over 290 Vickers.

The resistance of the nickel- and the cobalt-tungsten alloy to chemical attack is not much greater than that of either nickel or cobalt in the pure state, except that they are much more resistant to nitric acid. In the salt-spray test, coatings of cobalt-tungsten alloy show less porosity and afford better protection to steel than do ordinary nickel coatings. However, the nickel-tungsten alloys are inferior in protective value to nickel coatings.

Although tungsten alloys deposited from the solutions developed at the Bureau have not yet been utilized commercially, it is expected that they will find application on surfaces that require hardness and durability at elevated temperatures. Because of the excellent throwing power of the solutions, these coatings are more readily applied to irregular-shaped surfaces than is chromium plate. The electrodeposition section of the National Bureau of Standards will cooperate with those who are interested in plating small metal parts that can be subjected to a service test.



The most interesting feature of the electro-deposited tungsten alloys is their hardness. The effect of heat treatments at various temperatures on the hardness of cobalt-tungsten alloy is illustrated.

Extremely Wide-Angle Lenses for Aerial Mapping

It is well known that the effective exposure through a photographic lens is a maximum at the center of the negative and decreases rapidly toward the edge. Various techniques have been used in attempts to reduce this variation of image illumination at different points in the lens field, but all methods have required special photographic manipulation. Recent investigations by Dr. Irvine C. Gardner and Dr. Francis E. Washer of the Bureau's optical instruments laboratory have led to a more scientific and valid analysis of the causes of uneven negative exposure. A better understanding of such principles explains the discrepancies that other investigators have encountered in studying the variation of relative illumination from center to edge of the focal plane, and should aid materially in the design of photographic lens systems where even exposure is important. In particular, it puts the development of extremely wide angle lenses on a sounder basis and points the way toward substantial savings in airplane mapping.

The reduction of effective exposure arises from two causes, vignetting and the cosine-fourth-power law. When a beam of light passes obliquely through a photographic lens, the aperture of the diaphragm is usually not entirely filled with light which reaches the sensitive emulsion, because portions of the beam are obstructed by the ends of the lens barrel and the edges of the component lenses. This obstruction of the light is termed vignetting and is nearly always present for the marginal parts of a picture. The elimination of vignetting by making the diameter of the lens components large enough to permit the entire oblique beam to pass through the aperture of the diaphragm without obstruction presents certain prohibitive disadvantages. The lenses would be much larger and much more expensive. Furthermore, the correction for the aberrations in a lens is often such that the additional light admitted by the larger components would adversely affect the quality of the image. It is difficult to make a general statement regarding vignetting, inasmuch as each lens constitutes a special case which must be individually considered.

The second cause of the decreased effective exposure at the edge of the picture, the cosine-fourth-power law,[4] has some features that admit of generalization. In the absence of vignetting, if the lens is free from distortion, the effective exposure for points on the negative will be approximately proportional to the fourth power of the cosine of the angles between the corresponding object points and the center of the field.

This variation in effective exposure is not particularly important for such common applications of photography as portraiture or landscape photography, because the composition is usually such that the central parts of the picture are the most important, and a degradation of detail and lack of contrast in the marginal parts of the picture may even add to the quality of the composition. On the other hand, for professional motion picture photography the action may, on occasion, take place on any part of the screen, and an evenly exposed negative is desired. On studio sets it

[4] See Validity of the cosine-fourth-power law of illumination, Irvine C. Gardner, J. Research NBS **39**, 213 (1947) RP1824.

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is customary to correct for uneven exposure by properly distributing the lamps to increase the illumination of the objects that appear near the edge of the picture.

So far as the effect of the cosine-fourth-power law is concerned, it is evident that the diminution of exposure at the edge will be greater as the angle of the field of view is increased. To illustrate, if the field of view is 40 degrees (20-degree half-angle) the exposure at the edge of the field is approximately three-quarters that at the center. On the other hand, for fields of 90 and 110 degrees (half-angles of 45 and 55 degrees) the exposures at the edge of the field are one-quarter and one-ninth that at the center, respectively. When it is realized that these computed exposures are further reduced by vignetting, it is apparent that pictures with black-and-white film will be difficult, and, because of the less latitude, photographs with color film will be impossible for the wide-angle lens.

Dr. Gardner's investigations of the validity of the cosine-fourth-power law show that the cosine-fourth-power relation is not rigorously true but only approximate, and that departures from it can be achieved. When the object being photographed is at a great distance and the diaphragm is in front of the lens, the law holds for a distortion-free lens. If the diaphragm is within the lens, as in most commercial lenses, the entrance pupil, which is the image of the diaphragm formed by the part of the lens between it and the object, may be so affected by aberration that it is effectively larger for oblique beams. Consequently, the relative exposures of the marginal parts of the photographic field are significantly greater than would be predicted on the basis of the cosine-fourth-power law.

Perhaps the most important method of increasing the effective exposure at the edge of the field of a lens is by the introduction of a large amount of negative distortion. This result is one that can readily be understood. With negative distortion the scale of the picture for the outer portions is very much smaller than for the central parts of the picture. In effect, then, the outer parts of the picture may be said to be made with a lens of shorter focal length than the axial parts. Therefore, on this basis, the relative aperture is greater for the marginal parts than for the central part of the picture.

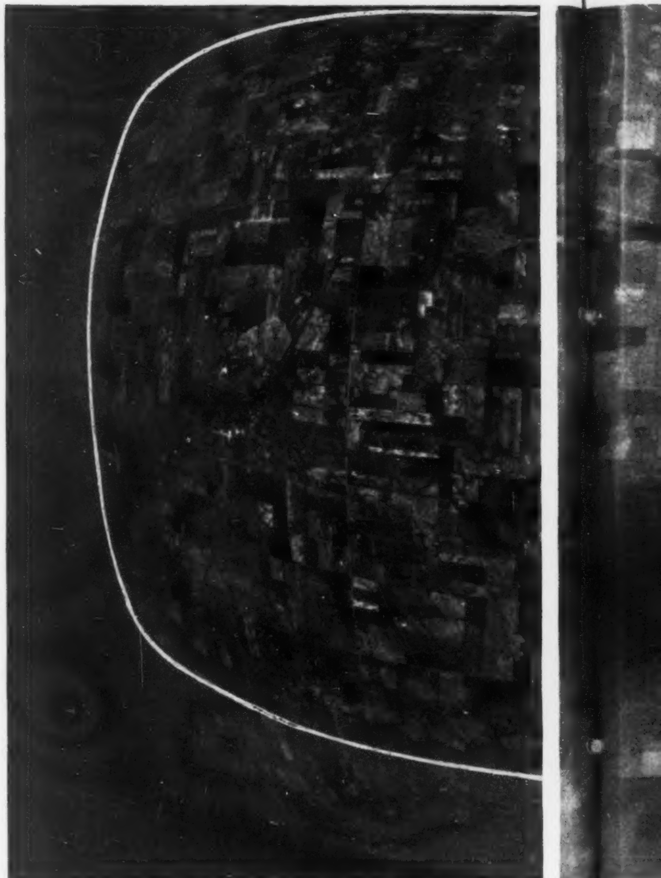
A quantitative consideration of the question indicates that the effective exposure will be uniform over the entire plate, in the absence of vignetting, even if the field of view is as great as 180 degrees, provided that the distortion is such that

$$r' = f \sin \beta. \qquad (1)$$

In this equation, r' is the distance from the center of the plate to a given image point, f is the focal length of the lens for the axial region of the picture, and β is the angle, measured in the object space, between the corresponding object point and the axis of the lens. Equation 1 applies rigorously only when the diaphragm is in front of the lens and the object is at an infinite distance.

For a distortion-free lens, the corresponding equation is

$$r' = f \tan \beta, \qquad (2)$$



Aerial photographs made with the Pleon wide-angle lens are c[...]cterize increases toward the outside edge. This effect is corrected for[...]nting that is, marginal parts of the picture are magnified more than [...] center of wide-angle lenses on a sounder basis and point the way to[...] subst

where the symbols are the same as in equation 1. It should be emphasized that the distortion indicated by equation 1 is very large and renders the picture quite useless for pictorial purposes unless it is subjected to a second process by which the distortion is removed. For example, if the focal length is four inches and $\beta =$ 45 degrees (total field of view equals 90 degrees), the distortion is more than one and one-eighth inches.

For many purposes this large distortion and the subsequent special optical projection method by which it is removed are too large a price to pay for the evenly exposed negative. Mapping by means of airplane photographs, however, is an important example in which the additional photographic manipulation is amply justified.

In the process of airplane mapping, the elevations of points are determined by a stereoscopic method. Consequently, each point of the terrain must appear in at least two photographs, thus providing an image for each of the observer's eyes, a requisite for stereoscopic

s are c cterized by a pronounced distortion of the image (left) that ed for nting (right) by a rectifier that introduces positive distortion; than center. Recent Bureau investigations place the development vay to substantial savings in airplane mapping. (Photo by USAF.)

observation. In practice, as an airplane proceeds in a straight flight, the exposures with a camera directed vertically downward are made at such intervals that two successive pictures overlap 60 percent in order to insure that each point will appear in two pictures. In making observations on a pair of photographs to determine contours or to determine the elevations of individual points, it is necessary that the photographs be carefully adjusted with respect to each other, a process termed orientation, in order that the values read from the plates may be correct.

Orientation is a difficult process, requiring considerable time of skilled personnel. After it has been accomplished, observations can be made on but half of each photograph, because only those objects common to the two photographs can be measured stereoscopically. This process is one of the large costs in aerial mapping. It is evident that if a camera with a larger field of view is used, fewer photographs will be required to cover a given area, and the cost of orientation will be correspondingly reduced. Consequently, in airplane mapping there is a great economic urge toward the use of wide-angle lenses. Lenses with large amounts of distortion can be economically used, provided they afford a markedly larger field of view.

Following the war, American intelligence groups in Germany brought back German wide-angle equipment which made use of large amounts of distortion to obtain a wider field of view. Although the focal length of the German lens, known as the Pleon, is only 2¾ inches, the large outer lenses are approximately a foot in diameter, with a field of view of 130 degrees. The law governing the distortion of this lens is given by the equation

$$r' = f\,\beta, \qquad (3)$$

the distortion being somewhat less than that of equation 1. Distortion in the negative is corrected for projection or printing by a specially designed optical device, in which light for the rectifying system is supplied by a high-pressure mercury arc. Because the optical system is not corrected for color, a filter is employed to admit approximately monochromatic light. In effect, the rectifier introduces positive distortion; that is, it magnifies the marginal parts of the picture more than the center, thus compensating the negative distortion in the original photograph. Actually a small amount of distortion remains in the print after rectification, and this distortion is, in fact, too large for American photogrammetric practice.

The German lenses utilize a principle embodied in a patent taken out by Dr. Gardner in 1936 (U. S. Patent No. 2037017). This principle has not yet been applied by American industry.

It has been mentioned that negative distortion tends to increase the uniformity of the effective exposure as compared with an exposure made with a distortion-free lens. It will be readily understood that large positive distortion, as in the optical system of the rectifier, exaggerates the unevenness of illumination. Greater magnification at the edge, as compared with the center of the picture, further decreases the exposure of the marginal points, which ordinarily would have received relatively less exposure. In laboratory copying apparatus, this is not a particularly serious characteristic, because the relative illumination of the different parts of the picture is under control and can be adjusted to give uniform exposure on the final photograph. In the German rectifier a filter of graduated density, lighter from the center outward, is used to balance the illumination.

Printed Circuit Techniques

In response to a widespread demand for technical information on printing electronic circuits, the National Bureau of Standards has published the first comprehensive treatment of this subject, entitled *Printed Circuit Techniques*, NBS Circular C468.

The methods of applying wiring and circuit components directly to an insulated surface, thus combining ruggedness with a high degree of miniaturization, are

presented under the topics Painting, Spraying, Chemical Deposition, Vacuum Processes, Die-Stamping, and Dusting. Performance and application details as well as precautions and limitations are discussed. Many applications and examples are given, including printed amplifiers, transmitters, receivers, hearing-aid subassemblies, plug-in units, and electronic accessories. A section on comparative performance of printed circuit elements is provided, and a bibliography covering processes, patents, applications, and other relevant matters is included as a supplement.

Circular C468 is now available from the Government Printing Office, Washington 25, D. C., at 25 cents a copy.

The Absolute Calibration of Vibration Pickups

During recent years the twin problems of vibration control and vibration measurement have assumed increasing importance. Structural engineers and others interested in the strength of materials have come to realize that continuous or intermittent exposure to vibration may adversely affect the useful life of a structure or machine. Operation of aircraft at high speeds introduces problems of vibration control with which the designer must continually contend. Studies of the vibration characteristics of engines, propellers, engine mounts, and structural components of the airplane must be made. In surface transportation such as railroads, busses, and cars, passenger comfort depends to a large extent on the absence of excessive and objectionable vibration. In acoustics, study of the transmission of vibration through building structures supplies important information concerning sound insulation and other building acoustic problems.

Of paramount importance and, indeed, occupying a key position in all investigations of this kind, is the vibration pickup of the electro-mechanical type, that is, a pickup that converts mechanical excitation into an electrical signal whose strength is proportional to the mechanical quantity being measured. In general, the pickup may be such that its electrical output is proportional to either the displacement, the velocity, or the acceleration of the mechanical vibration under study. If useful quantitative data are to be obtained from the vibration pickup, it is necessary to know the proportionality factor between the mechanical quantity under observation and the electrical output of the pickup. This immediately brings up the question of calibrating such a device.

Heretofore, accurate calibrations of such instruments have been generally restricted to low frequencies, below about 100 cycles per second, where it is possible by visual observation to determine the amplitude of motion of a vibration exciter. Combining this with a measurement of the electrical signal from the pickup, the calibration constant may be evaluated. For frequencies in the acoustic range, say up to 5,000 cycles per second, the amplitudes of vibration that are ordinarily encountered are very small. For example, the amplitude of vibration of a concrete wall at 1,000 cycles per second, measured at the National Bureau of Standards, was of the order of magnitude of 10^{-7} cm, a quantity that is almost comparable to atomic dimensions. For audio frequencies, then, it is rather difficult to obtain a vibrating platform of known amplitude with which a vibration gage may be calibrated.

Although it is rather difficult to measure small mechanical displacements directly, it is possible to make electrical measurements with considerable precision. Accordingly, early in 1944, Albert London of the Bureau's sound laboratory adapted to the problem of calibrating vibration pickups the reciprocity technique first successfully applied to an absolute calibration of microphones.[5] In this method, difficulties associated with the precise measurement of small acoustic pressures are completely circumvented. It is only required to make two electrical measurements and to know the volume of a cavity and the modulus of elasticity of a gas. Similarly, in the vibration pickup case, it will be shown that it is necessary to make electrical measurements and mass determinations.

As applied to the present discussion, the reciprocity principle states that if a vibration pickup has a calibration constant K given by

$$e = Kv, \tag{1}$$

where e is the emf generated by the pickup when it is subjected to a velocity v, then the pickup, when its function is reversed,[6] will generate a force f, when a current i is introduced into its electrical terminals, given by

$$f = Ki. \tag{2}$$

In equations 1 and 2 the question of the phase between currents, forces, emf's, and velocities is not considered. If the pickup is electromagnetic in nature, i. e., mechanical velocities are converted to emf's by means of magnetic coupling, equation 2 has to be modified to read $f = -Ki$. If it uses electrostatic coupling, equation 2 is correct as it stands. The $\pm$ phase determining sign will be neglected in what follows, as the discussion will be restricted to a determination of the magnitude of K only, and not its sign.

Suppose now that in addition to the pickup under calibration, another reversible pickup is available. With the two pickups the following experiments are performed.

(1) A determination of the relative outputs of the two vibration pickups when subjected to the same vibra-

[5] R. K. Cook, Absolute pressure calibration of microphones, J. Research NBS 25, 489 (1940) RP1341.

[6] Reversible, linear, bilateral electromechanical pickups are considered here. For a discussion of the properties of linear bilateral pickups and a simple proof of the reciprocity theorem, see preprint paper No. 47–A–5 of the Journal of Applied Mechanics, entitled The absolute calibration of electromechanical pickups, by H. M. Trent (Dec. 1947). This preprint outlines a method of calibrating pickups, entirely equivalent to the method described in the present paper, which was first investigated at the National Bureau of Standards in 1944.

tion. Evidently, if subscripts 1 and 2 refer to pickups 1 and 2, respectively, then from equation 1 this experiment gives for the ratio K_1/K_2,

$$K_1/K_2 = e_1/e_2, \tag{3}$$

where e_1/e_2 is the ratio of the measured emf's.

(2). A determination of the output of one pickup when driven by the second pickup. In this experiment the two pickups are rigidly fastened together, a current i_1 is introduced into pickup 1, and the emf generated by pickup 2, e'_2, is observed. Primes will be used to refer to the driven pickup, and unprimed quantities to the driver pickup. From equation 2, a force f_1 is generated by pickup 1. This force acting on both pickups produces a velocity v_{12} given by

$$f_1 = v_{12}\ (Z_1 + Z_2), \tag{4}$$

where Z_1 and Z_2 are the mechanical impedances of pickups 1 and 2, respectively. Mechanical impedance is here defined as the complex ratio of force acting on a mechanical element to velocity produced in the element. As the velocity v_{12} acts on pickup 2, an emf e'_2 will be generated in this pickup which from equations 1 and 2 is given by

$$e'_2 = K_2 v_{12} = K_2\ \frac{f_1}{Z_1 + Z_2} = \frac{K_2 K_1 i_1}{Z_1 + Z_2}. \tag{5}$$

In this experiment the ratio e'_2/i_1, the so-called transfer impedance, may be measured electrically. Equation 5 combined with equation 3 may be used to obtain an expression for either K_1 *or* K_2, provided the unknown impedance $Z_1 + Z_2$ can be eliminated from equation 5. For this purpose experiment (3) is required.

(3). This experiment is the same as (2) with a mass, M, interposed between the two pickups. As the impedance of the mass is $j\omega M$, where $\omega = 2\pi$ times frequency, and $j = \sqrt{-1}$, equation 5 is modified to

$$E'_2 = \frac{K_2 K_1 I_1}{Z_1 + Z_2 + j\omega M}. \tag{6}$$

Capital letters for e and i are used here to identify experiment (3).

$Z_1 + Z_2$ may be eliminated from equations 5 and 6 to give an expression for $K_1 K_2$ in terms of the readily measurable quantities M, i_1/e'_2, I_1/E'_2. The relation that results, when combined with equation 3, produces an expression for K_1 or K_2 that depends on the electrical quantity e_1/e_2 in addition to the three quantities above. Thus, a measurement of three electrical ratios together with a measurement of mass is sufficient to perform the calibration.

In preliminary experiments conducted at the Bureau in 1944, two moving coil velocity pickups of identical design were calibrated by this technique. The characteristics of these two pickups were such, and the experiments were so carried out, as to give, in addition, a determination of the impedance of the pickups, the quantity $Z_1 + Z_2$. For this purpose several different masses were used in experiment (3).

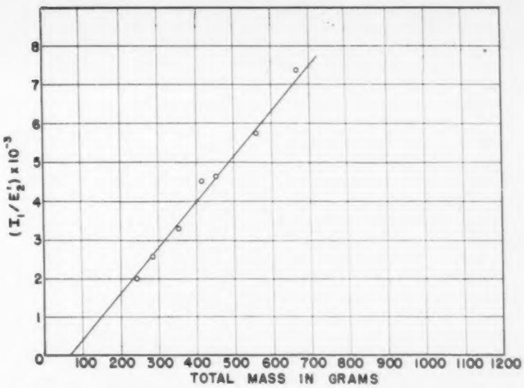


Figure 1. Variation of I_1/E'_2 (amp/volt) with total mass of system at a frequency of 100 cycles per second.

Figure 1 shows the result of such an experiment at a frequency of 100 cycles per second. The ordinate is the ratio of the input current of the driver pickup to the output voltage of the driven pickup, I_1/E'_2. The abscissa is the *total* mass of the system including the mass of both vibration pickups. The lowest point on this graph, therefore, corresponds to experiment (2) with zero additional mass, i. e., $M=0$, the mass of both pickups being 245 grams.

Several conclusions may be drawn from the fact that all of the points fall on a straight line. As the quantity $K_1 K_2$ is constant at any one frequency, equation 6 is the equation of a straight line in the plot of variables I_1/E'_2 versus M, provided the mechanical impedance term $Z_1 + Z_2$ is purely imaginary in nature. Thus, it may be concluded that for these two pickups the mechanical resistance of the units is negligible. If the straight line went through the origin, the admittance would simply be that due to M_0, the sum of the masses of both pickups. In general, the line does not go through the origin so that

$$Z_1 + Z_2 = j\omega\ (M_0 - m), \tag{7}$$

where m is the intercept of the straight line along the mass axis. The value of m obtained at different frequencies is given in figure 2. Evidently the appearance of the negative term in equation 2 is due to the compliance of the pickup. The fact that the pickup impedance includes an elastance term is rather surprising, inasmuch as it is ordinarily assumed that a seismic pickup, working above its natural frequency, in which the voltage output is due to a light moving-coil, will be strictly mass-controlled. Actually the experimental results show that there is more than one natural frequency in the frequency range over which it was tested. This would account for the existence of the elastic components in the impedance.

In figure 3 a plot of the transfer impedance, in logarithmic units, 20 log (e_2'/i_1), (i. e., experiment 2), is given. In figure 4 the relative response of the two pickups is plotted (experiment 1), and figure 5 is the result of the reciprocity calibration for one of the pick-

ups. At the lowest natural frequency of about 25 cycles per second, the pickups are well-behaved. However, another resonant frequency occurs in the range between 120 and 160 cycles per second where the response is irregular in nature. As the two pickups may have slightly different resonant frequencies, the interference of two slightly displaced resonance curves may cause a rather erratic relative response curve. The calibration constant, plotted in figure 5, was calculated by substituting for $Z_1 + Z_2$ in equation (5) from equation (7). For this special case, the expressions for the magnitude of K_1 and K_2 (disregarding phase) are:

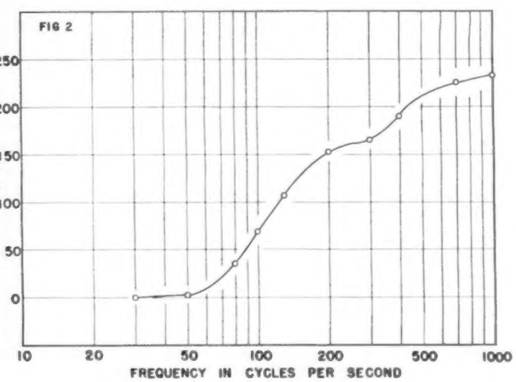
$$K_1^2 = \omega \ (M_0 - m) \ (e_1/e_2) \ (e_2'/i_1) \tag{8}$$

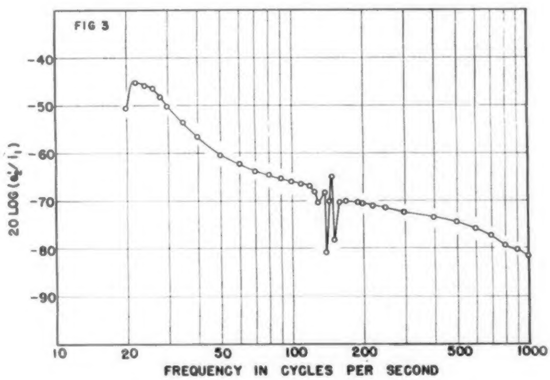
$$K_2^2 = \omega \ (M_0 - m) \ (e_2/e_1) \ (e_2'/i_1). \tag{9}$$

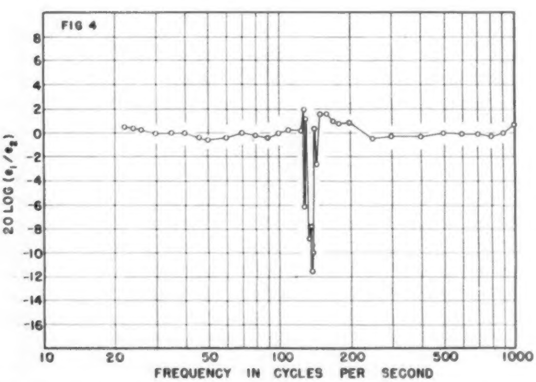
The calibration constant of the device, which, as given by the manufacturer, is supposed to be independent of frequency, is also indicated in figure (4). In the region from 120 to 160 cycles per second, the calibration was not reproducible and hence is left blank.

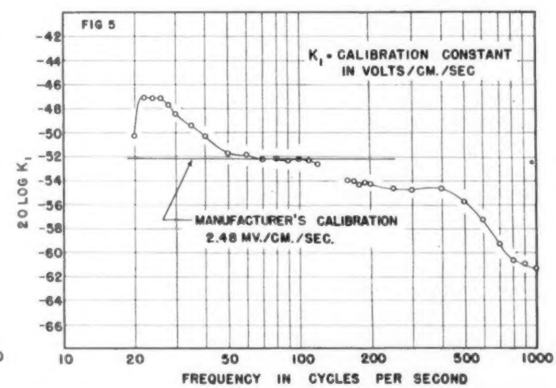
In addition to the experiments conducted on the two velocity pickups (discussed above), back-to-back calibrations, that is, one pickup used as a driving source for the other pickup, were tried, using combinations of one velocity-type pickup, two crystal or piezoelectric pickups, and one variable-reluctance type pickup. None of these combinations was successful. All of the pickups were excellent reversible sources. However, the variable-reluctance type was sensitive to orientation, and the crystal pickups were variable with respect to static pressure applied across them. The cause for the erratic behavior of such pickups needs further investigation to determine whether this limitation is inherent in the method or in the pickups.

Extension of this preliminary investigation, postponed because of defense activities, will include development of an independent absolute method for calibrating pickups in order to provide confirmation of these results. The procedure that is contemplated is to fasten the pickup on a vibrating piston, which is itself part of a small cavity. The motion of the piston will develop an acoustic pressure in the cavity whose magnitude may be determined by a microphone previously calibrated by the reciprocity technique. From the amount of pressure developed, the amplitude of vibration of the piston may be determined so that an absolute calibration of the pickup may be obtained.









The absolute calibration of vibration pick-ups. Figure 2. Variation of m with frequency, where m is the intercept, on the mass axis, of the straight line I_1/E'_2 versus total mass (as in figure 1). Figure 3. Transfer impedance of the two pick-ups with $M=0$. Figure 4. Relative response of the two pick-ups. Figure 5. Frequency calibration of one of the vibration pick-ups.

New Electrical and Photometric Units in Effect

January 1, 1948 marks the beginning of a new era in the field of electrical and photometric measurements, because from that date forward, all over the world, new sets of units* will be used for the precise expression of quantitative measurements. In the electrical field this means the abandonment of the so-called "international" electrical units which have been in use since January 1, 1911, and the introduction of "absolute" units which are by definition the closest possible approximation to the ideal values which would be in exact concordance with the fundamental mechanical units of length, mass, and time.

In photometry the new units are based on two elements. The first is the brightness of a "black-body" radiator heated to the freezing point of platinum. This basic and reproducible standard is commonly called the "Waidner-Burgess" standard after the two members of the Bureau staff who first prepared it. The new candle is defined as such a value that this standard has a brightness of 60 candles per square centimeter. The second element is the standard luminosity curve recommended by the Bureau in 1923 and used when extending the new basic unit to lights of other colors. The new photometric units replace the older units based on an arbitrary assignment in 1909 of values of candlepower to a group of carbon filament electric lamps.

In both fields the new units differ only slightly from the old ones so that the change will affect only scientific measurements of high precision.

*See Changes in electrical and photometric units, NBS Technical News Bulletin **31**, 49 (May 1947).

NBS Scientists

Dr. John H. Curtiss, who has been the Director's Assistant in applied mathematics, has been named chief of the National Applied Mathematics Laboratories, recently set up at the Bureau to serve primarily as a national center for research, training and service in applied mathematics for units of the Federal Government and private industry. Dr. Curtiss came to the Bureau of Standards from the Bureau of Ships, Navy Department, where he developed and later headed a section devoted to the application of modern statistical methods to problems in naval engineering and quality control. He is the author of a large number of technical papers on such subjects as probability and statistics, and the theory of functions.

Dr. E. W. Cannon has been appointed chief of the Bureau's Machine Development Laboratory, according to an announcement by the Director. This group is primarily engaged in formulating mathematical performance specifications for the high speed electronic computing machines now under construction by the Bureau. It also serves as a coordinating agency for all the scientists working on phases of the program. Dr. Cannon is both an electrical engineer and a mathematician. A naval officer during the war, he first served as an engineering specialist directing work on the de-magnetizing of ships to protect them from magnetic mines. In 1945 he was transferred to the Bureau of Ships and became a statistical engineering officer.

Dr. Irving A. Denison has been appointed chief of the Bureau's Underground Corrosion Section, where he will direct fundamental studies of underground corrosion utilizing the data from extended field tests. Dr. Denison has given special attention to the correlation of soil characteristics with corrosion of metals in soils. His work on the electrical properties of corrosion circuits, measurement of current requirements for cathodic protection of pipe lines, and laboratory and field tests of corrosion and corrosion prevention has been reported in a number of papers in scientific journals.

NBS Publications

Periodicals [9]

Journal of Research of the National Bureau of Standards, volume **39**, number 6, December 1947. (RP1842 to RP1849, inclusive.)

Technical News Bulletin, volume **31**, number 12, December 1947. 10 cents.

CRPL–D40. Basic Radio Propagation Predictions for March 1948. Three months in advance. Issued December 1947. 10 cents.

See footnotes on following page.

Nonperiodical

Research Papers [9, 10]

RP1835. Deposition of nickel and cobalt by chemical reduction. Abner Brenner and Grace Riddell. 10 cents.

RP1836. Calculations on countercurrent electromigration. G. Breit and F. L. Friedman. 10 cents.

RP1837. Activity coefficients in aqueous mixtures of phosphates with sodium chloride, sodium bromide, and sodium iodide, and the pH of phosphate buffer solutions. Roger G. Bates. 10 cents.

RP1838. Thermal expansion of some copper alloys. Peter Hidnert and Harrison S. Krider. 10 cents.

RP1839. Alkylbenzenes in the C_9 fraction from seven representative crude petroleums. A. F. Forziati and Frederick D. Rossini. 10 cents.

RP1840. Experimental study of the Koppers-Hinckley-Podbielniak apparatus and method for the determination of conjugated dienes. Martin Shepherd, Richard Thomas, Shuford Schuhmann, and Vernon H. Dibeler. 15 cents.

RP1841. Measurements of heat of vaporization and heat capacity of a number of hydrocarbons. Nathan S. Osborne and Defoe C. Ginnings. 15 cents.

Circulars [9]

C468. Printed circuit techniques. 25 cents.

Simplified Practice Recommendations [9]

R6–47. Files and rasps (American pattern, and curved-tooth milled files). (Supersedes R6–45.) 10 cents.

R8–47. Ferrous range boilers, expansion tanks, and solar tanks. (Supersedes R8–42.) 5 cents.

R85–47. Adhesive plaster. (Supersedes R85–43.) 5 cents.

R185–47. Pipe fittings (Gray cast iron, malleable iron, and brass or bronze). (Supersedes R185–42.) 10 cents.

R228–47. Pallets for the handling of groceries and packaged merchandise. 5 cents.

Letter Circulars [11]

LC884. Mathematical tables. (Supersedes LC777.)

Articles by Bureau Staff Members in Outside Publications [12]

High-temperature X-ray diffraction apparatus. A. Van Valkenburg and H. F. McMurdie. Am. Ceramic Soc. Bul. (2525 North High Street, Columbus 2, Ohio) **26,** 139 (May 15, 1947).

Product quality specifications. F. E. Powell. Am. Ceramic Soc. Bul. **26,** 181 (June 15, 1947).

Standard buffer solutions. George G. Manov. Symposium on pH measurement. Tech. Pub. No. 73, American Society for Testing Materials (1916 Race Street, Philadelphia 2, Pa.) 79 pages (1947).

Report on buffer solutions. George G. Manov. J. Assoc. Official Agr. Chem. (Box 540, Benjamin Franklin Station, Washington, D. C.) **30,** 500 (1947).

2,2,5,5-Tetramethyl-3-hexene. F. L. Howard, T. Mears, A. Fookson, and P. Pomerantz. J. Am. Chem. Soc. (1155 Sixteenth Street NW., Washington 6, D. C.) **68,** 2121 (1946).

Ionization yields of radiations. II. The fluctuations of the number of ions. U. Fano. Physical Review (57 East Fifty-fifth Street, New York 22, N. Y.) **72,** No. 1, 26 (July 1, 1947).

Polyurethanes. Otto Bayer, translated by Mrs. I. G. Callomon and G. M. Kline. Modern Plastics (122 East Forty-second Street, New York 22, N. Y.) **24,** No. 10, 149 (June 1947).

Viscosities of solutions of cellulose acetate in solvent-precipitant mixtures. S. G. Weissberg and R. Simha. J. Colloid Science (125 East Twenty-third Street, New York 10, N. Y.) **2,** 305 (April 1947).

Relabeling of the *cis* and *trans* isomers of 1,3-dimethylcyclohexane. F. D. Rossini and K. S. Pitzer. Science (1515 Massachusetts Avenue NW., Washington 5, D. C.) **105,** 647 (1947).

Treatments for metal surfaces prior to painting. E. F. Hickson and W. C. Porter. Product Engineering (330 West Forty-second Street, New York 18, N. Y.) **18,** No. 8, 128 (August 1947).

Examinations of absolute and comparative methods of polarographic analysis. John Keenan Taylor. Analytical Chemistry (1155 Sixteenth Street NW., Washington 6, D. C.) **19,** 368 (1947).

Analysis of natural gas by volumetric chemical methods and by the mass spectrometer. Martin Shepherd. Analytical Chemistry, **19,** 635 (1947).

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[9] Send orders for publications under this heading only to the Superintendent of Documents, Government Printing Office, Washington 25, D. C. Annual subscription rates: Journal of Research, $4.50 (foreign $5.50); Technical News Bulletin, $1.00 (foreign $1.35); Basic Radio Propagation Predictions, $1.00 (foreign $1.25). Single copy prices of publications are indicated in the lists.

[10] Reprints from November Journal of Research.

[11] Available on request from the National Bureau of Standards, Washington 25, D. C. Letter Circulars are prepared to answer specific inquiries addressed to the Bureau, and are sent only on request to persons having a definite need for the information. The Bureau cannot undertake to supply lists or complete sets of Letter Circulars or send copies automatically as issued.

[12] These publications are not available from the Government. Requests should be sent direct to the publishers.

Periodicals of the National Bureau of Standards

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The *Technical News Bulletin* presents concise articles on current work in NBS laboratories. The articles are brief, with emphasis on scientific results and their technologic significance. Also included are accounts of important national and international meetings, and a bibliography of Bureau publications during the preceding month.

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